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Summary

Background

It is the policy of the Department of Defense "that individual Service members possess the ...muscle strength... to successfully perform in accordance with a Military Service-specific mission and military specialty." Robertson and Trent (1985) and others have verified that the majority of physically demanding military tasks are those involving materials handling. The most common tasks are lifting and carrying. These are tasks for which muscle strength is a major determinant of success. However, the Services do not generally measure strength as part of their physical fitness testing, because of issues of safety, and desires to have tests which can be administered in the field.

The Services have, for 16 years, used body composition as the basis for weight control policy. There is a familiarity with the concepts and notions of the nature of body composition within the Services. Body composition variables, specifically fat-free mass and fat mass have been shown to be related to materials handling performances. It is the purpose of this report to determine these relationships, and suggest ways in which they might be used for safe, field deployable methods for estimation of materials handling performance.

Methods

One hundred and two active duty Navy and Marine Corps personnel were recruited for this study (64 men, 38 women). These participants had the following measurements made: (1) Their strength was determined as one-repetition maximal lifts (1RM) for bench press, shoulder press, leg press, arm curl, lat pull-down, and for the incremental lift machine (ILM) used in Air Force occupational screening. (2) Aerobic capacity was assessed as maximal rate of oxygen consumption, and time for the 1.5 mile run. (3) Performance on three job-task simulations was measured. The tasks were box lifts to knuckle and elbow height, and a box carry task. (4) Anthropometric evaluation consisted of measurement of stature and body weight. (5) Body composition was determined from two compartment analysis of body density, determined from body weight and body volume from underwater weighing.

Results and Discussion

Correlations between strength measures and performance on the lifting tasks averaged 0.82 (range 0.76 to 0.89). Of the body composition measures (fat-free mass, fat mass, percent body fat, and body weight), fat-free mass had the highest correlation with both lifting and carrying performances. Therefore, models to predict lifting capacity were based on fat-free mass. The highest correlations between strength measures and lifting performance were with the ILM. Therefore, the ILM was used to represent the strength dimension in developing comparative models of task performance. Following the suggestions of Robertson, a predictive model based on body weight, alone was developed. Regression equations to predict lifting performances from strength, fat-free mass, and body weight were:

Lift to knuckle height	= 1.06 x ILM + 27.04,	R^2 = 0.72, SEE = 11.99
	= 1.52 x FFM - 8.57,	R^2 = 0.63, SEE = 13.97
	= 1.04 x WT + 4.02	R^2 = 0.44, SEE = 17.11
Lift to elbow height	= 0.81 x ILM + 15.44	R^2 = 0.79, SEE = 7.48
	= 1.15 x FFM - 11.50	R^2 = 0.71, SEE = 8.81
	= 0.81 x WT - 3.84	R^2 = 0.53, SEE = 11.13

where all variables are in kg.

The predictive models utilizing ILM were slightly better than those utilizing fat-free mass. The models utilizing body weight were clearly the least precise. Based on these findings, a series of logistic regression calculations were carried out to predict the probabilities of completing specific lifts to knuckle and elbow heights. These results are presented in tabular form, and could form part of a series of tables which could be used to select military personnel for performance of materials lifting.

The best regression to predict the carrying task from body composition variables was
Box carry distance = 7.463 x FFM - 7.367 x FM + 752.886, R2 = 0.403, SEE = 122.78 m
Where FM is the body fat weight. Better predictive models have been developed utilizing aerobic capacity measures with either ILM or FFM. R2 values for these models are on the order of 0.55. The model developed here is not practical, given the wide variety of carrying tasks.

Conclusions

It appears that fat-free mass can be used to estimate ability to perform manual materials handling tasks. In the case of lifting, logistic models can be used to determine acceptable levels of fat-free mass for specific tasks: lifting heights and weights. In the case of carrying tasks, simplifying principles need to be developed before predictive models can be developed.

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Introduction

The purpose of this paper is to explore the use of fat-free mass, determined from body composition analysis, to provide a safe method for prediction of performance of materials handling tasks in the military services.

The policy of the Department of Defense (DoD) is "that individual Service members possess the cardiorespiratory endurance, muscular strength and endurance, and whole body flexibility to successfully perform in accordance with a Military Service-specific mission and military specialty." Additionally, the Military Services are required "...to design physical fitness training and activities to maintain a level of physical fitness that promotes combat readiness...," and to "...incorporate job-specific physical standards into their respective physical fitness programs." (Department of Defense, 1995)

In 1985 Robertson and Trent concluded a Navy study wherein they found that physically demanding jobs in the Navy were manual materials handling tasks, and that strength was the primary physical attribute needed to accomplish such tasks. Robertson and Trent (1985) found that carrying while walking was the most common category of physically demanding tasks making up 48% of those reported. Lifting tasks were the second most common at 20% of the reported physically demanding tasks. A review of occupational demands in the NATO forces (NATO, 1986) revealed "...manual materials handling, basically lifting and carrying, is the common denominator for physical effort in many trades." The report states that 70% of the trades in the Canadian forces require lifts that would be described as "moderately heavy" by U.S. Department of Labor standards. Thus, it is adequate amounts of strength that appear to be the key to carrying out physically demanding tasks in Military Services.

Recent work by Vickers indicates that working in more physically demanding Navy jobs is associated with greater rates of low back injuries (Vickers, Hervig and White, 1997). Vickers (personal communication) unpublished analysis of physical fitness data collected by Marcinik and coworkers aboard ships (Marcinik et al, 1985), suggests that sailors in more physically demanding ratings may not have more strength than those in less demanding jobs. His findings suggest that sailors in more demanding jobs may not have adequate strength to reduce the risk of injury on the job to levels of less demanding jobs. The rate of injury on the job might be reduced if strength was measured among Navy personnel for selection or screening for, physically demanding jobs.

The DoD currently does not require the Services to include strength testing in their physical fitness tests. The Services generally have not favored such testing because they desire fitness tests that can be performed in the field, and that do not require equipment in order to be performed. However, the Air Force has recently increased the facilities available for physical conditioning and testing at its bases. It is now practical for the Air Force to carry out strength testing, and they are now considering adding it to their fitness test (Palmer and Soest, 1997).

The Services, in general, do not screen for physical fitness to enter specific occupations. Exceptions are Special Forces, divers, and aviators. Only one Service, the Air Force, tests the strength of its candidates prior to assignment to a specific occupation. The Air Force administers a Strength Aptitude Test (SAT) (Ayoub, et al., 1987) in the Military Examination and Processing Stations (MEPS). The SAT is the measurement of the one-repetition maximal lift to approximately shoulder height using a maneuver similar to a "clean and jerk" on a machine with an adjustable weight stack designed for this purpose (McDaniel, Kendis and Madole, 1980). Each Air Force Specialty Code (AFSC) has an associated SAT performance standard.

Testing of maximal physical capacity prior to actual entrance into the Service is perceived as risky. It is possible for applicants to be injured during maximal testing, and Service aspirants are not eligible for military medical care, prior to entry.

Therefore, it would be useful if the Services had a risk free method of estimating an individual's strength prior to entry, and a field method of estimating strength as part of periodic fitness assessments. Analysis of body composition may provide such a method.

Table 1. **Body composition analysis based on anatomical and chemical components**

Anatomical	Chemical
Adipose tissue	Fat
Muscle	Nitrogen/Protein
Bone	Minerals
Skin	Water
Residual	

For the past 17 years, as part of DoD policy, all services have weight control programs based on body composition standards. The intent of body composition analysis is to divide the body into compartments that have meaning relative to structure or function. The two most common bases for defining compartments are anatomical structures and chemical composition (Heymsfield, et al., 1993). Table 1 provides examples of body compartments based on anatomical and chemical divisions. A comparison of the anatomical and chemical components in the first three rows of Table 1 highlight the contrast between the two methods of body composition analysis. The body component that is associated with the level of fatness is the adipose tissue in the anatomical model. The tissue consists not only of the fat molecules, but also the cells that contain them and the other elements of those cells (water, dissolved solids, plasmids, etc). Fat that is not contained within the adipose tissue (e.g. myelin in the nervous system) is not included in this compartment. In the chemical model, the fat compartment is composed of all the chemically extractable fat in the body. This includes all the fat molecules in the body, but not the cells and other structures that contain them.

The DoD uses body composition analysis as the basis for weight control because it is the amount of fat, rather than weight itself, that appears to be associated with health risks (NIH, 1985), and because body weight can be a poor estimator of fatness. Individuals for whom body weight is elevated due to the presence of a large muscle mass (e.g. weightlifters), do not have the same health risks as others of the same weight but for whom the major component is excess fat.

The number of compartments into which the body is divided during body composition analysis usually varies from two to four. The compartments are expressed as an absolute mass or as a percent of body mass. The most common form of body composition analysis is one that divides the body into two components: a fat component, and a nonfat component. In the anatomical model, this corresponds to adipose tissue mass and the remaining mass, usually referred to as the "lean body mass." In the chemical model the body is divided into the fat mass and a residual referred to as the "fat-free mass."

In a two-compartment analysis, the compartment associated with carrying out physical work is the lean body, or fat-free mass. It is this mass that contains the mass of the muscular and skeletal systems, the systems that are directly responsible for accomplishing physical work, and the circulatory and respiratory systems that provide metabolic support the musculoskeletal system. The musculature, skeleton and connective tissue make up approximately 70 percent of the lean body mass (Pace, 1974). The circulatory and respiratory systems comprise an additional 12 percent. Thus, 82 percent of the lean body mass is associated with structures central to performing useful work. The magnitude of the lean body mass, then, should be a useful indicator of physical capacities.

Several investigations have shown positive, significant correlations between lean body mass (or fat-free mass) and maximal lifting capacity (Teves et al., 1985; Sharp, 1992; Myers, et al., 1983) or pushing, torquing, and carrying (Harman and Frykman, 1992). These correlations range from 0.35 for maximal torque production to 0.64 for maximal lifts to elbow height, within a single gender group. In these lifting studies, it has also been shown that percent fat is poorly correlated (0.06 £ r £ 0.26) with lifting, torquing and pushing performance (Harman and Frykman, 1992).

Lean body mass also has been shown to be positively correlated with load carriage performance. Mello and coworkers (1988) find correlations of -0.55 £ r £ -0.39 with times to complete marches of distances ranging from 2 to 12 km with full backpack. Note that in this instance a negative correlation means increased lean mass is associated with a faster marching pace. However, unlike the case in lifting tasks, these authors found percent fat to be significantly related to march time for distances above 2 km (range of correlations was 0.29 to 0.48). The positive correlations mean greater percent fat values were associated with a slower march pace. This finding is reasonable given that whenever the body mass is moved as part of a task, the fat mass is part of the "dead weight" that must be moved.

It is clear that lean body mass is associated with strength performances, and both lean and fat masses are associated with carrying performance. However, previous authors have not developed models to utilize this relationship to predict performance of the materials handling tasks that are components of physically demanding jobs in the military. The purpose of this study was to develop models predicting performance on three materials handling tasks from fat-free mass and fat mass, and to compare those models with models utilizing direct measurements of strength and aerobic capacity. Following suggestions of Robertson (1982), that body mass is sometimes a good predictor of performance of Navy strength tasks, a further comparison to models utilizing body mass instead of fat-free mass for prediction of strength tasks, also is offered.

Methods

Beckett and Hodgdon (1987b) have reported other aspects of this study previously. That work focused on prediction of lifting and carrying capacities from physical fitness measures. This report extends the analysis of the data set to prediction from body composition variables.

Subjects.

This study was reviewed and approved by the Naval Health Research Center Committee for the Protection of Human Subjects. Participants in this study were 102 active-duty Navy and Marine Corps personnel, recruited from the southern California area. All study applicants were informed about the aims of the study, the procedures involved, and the risks associated with participation. Those from

Table 2. Participant Physical Characteristics

	Men (N = 64)	Women (N = 38)
Age (yr.)	27.8 ±3.9	27.6 ±4.1
Height (cm)*	177.8 ±7.0	165.4 ±6.0
Body Mass (kg)*	81.5 ±12.2	61.4 ±7.6
Body Fat Content (% of mass)*[1]	17.4 ±7.9	24.1 ±7.3

* Gender differences significant ($p < 0.05$)

[1] Body fat content determined from hydrodensitometry and application of the Siri 2-compartment model.

whom information was collected gave their consent to participate. As a safety measure subjects were screened for adequate strength. The study design called for performance of a task in which a 34 kg box was carried. The box was to be carried approximately 50% of the time. The work of Monod (1985) suggested that individuals who could perform this work safely should be able to lift twice the weight of the box to be carried. Therefore, we tested potential subjects with an isometric lift at elbow height. Those who could not exert 68 kg of force were precluded from participation. Physical characteristics of the study participants are provided in Table 2.

Measures.

The following measures were obtained on all subjects:

Strength

Dynamic strength measures included one-repetition maximums (1RM) for bench press, shoulder press, leg press, arm curl, and lat pull-down. These measures were obtained using a UniversalÔ multi-station exercise machine. Initial weights for each event were set as a fixed percentage of the participant's fat-free mass. The 1RM values were usually reached within 4 trials. 1RM was also determined for a lift to 152 cm on the U.S Air Force Strength Aptitude Test machine. In this paper, the Air Force machine will be referred to as the incremental lift machine (ILM).

Aerobic Capacity

Aerobic capacity was measured as the maximal rate of oxygen consumption ( ), determined from open-circuit spirometry measures obtained during a graded treadmill exercise test. Additionally, the time to run 1.5 miles was measured as a field indicator of aerobic capacity.

Job Task simulations

Three job task simulations were used: a 1RM box lift to knuckle height, a 1RM box lift to elbow height, and a box carry for distance. A rectangular metal box 33cm long, by 25 cm wide, by 20 cm in height was constructed. A solid bar handles (20 cm long and 3.3 cm in diameter) was attached to each end of the box. The two handles were 46 cm apart, and positioned 9 cm above the base of the box. The box weighed 5.67 kg, empty. Adding bags of lead shot of known masses increased the weight of the box.

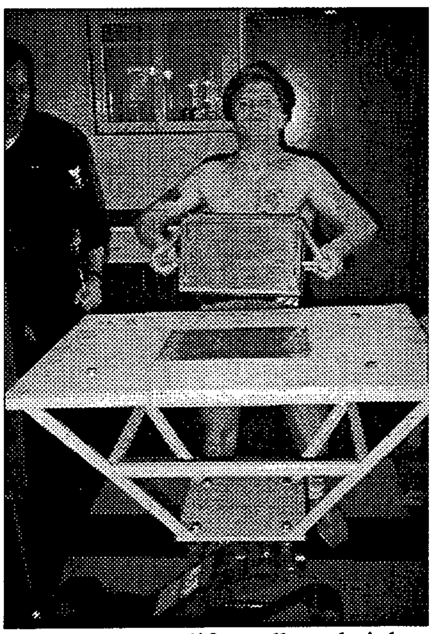

Figure 1. Box lift to elbow height

To measure maximal box lifting performance, an adjustable platform was constructed (see fig. 1). To test maximal lifting capacity at elbow height, the height of the platform was adjusted to match the height of the base of the box from the deck when the elbows were flexed at a 90° angle. For the knuckle-height lift, the platform was adjusted to be even with the base of the box when the participant was standing upright holding the box with the arms extended downward. The maximum weight that could be lifted during this exercise was 113.4 kg. This was the maximum amount of lead shot that could be put in the box. Thirteen participants were able to lift this mass.

The box carry consisted of two bouts of carrying the box described above on alternate trips of a 51.4-m course. The task was designed to simulate offloading stores from a pallet. Participants picked up the box, loaded to 34 kg, from the platform adjusted to mid-thigh height, carried it along an out-and-back course, returned it to the platform, then retraced the course without the box. Work was performed

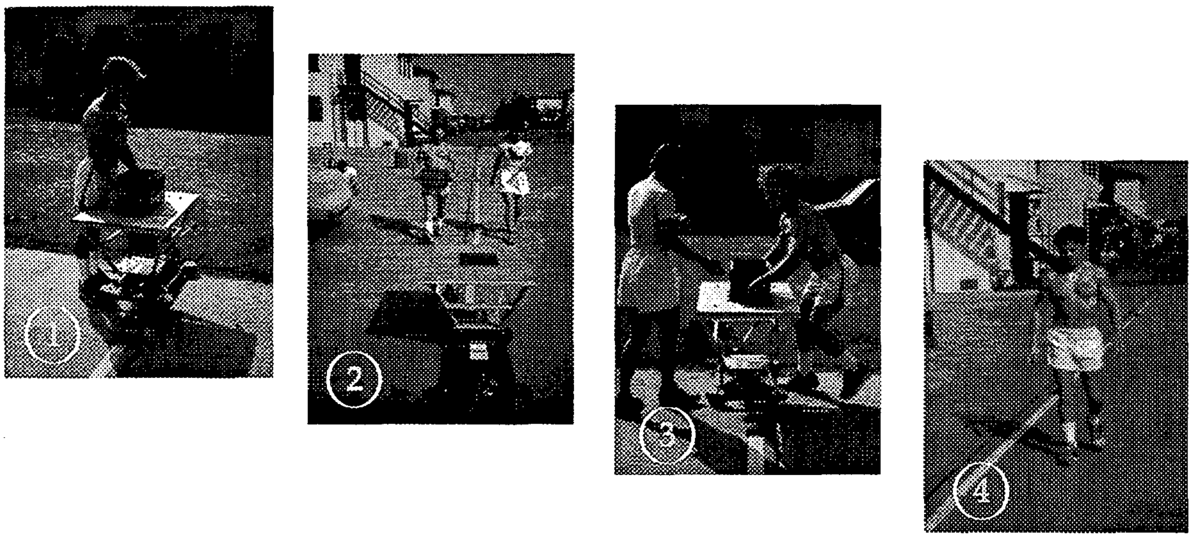

Figure 2. Box carry task. The participant picks up the weighted box (panel 1), carries it out and back along a measured track (panel 2), sets the box down on the platform (panel 3), and walks out and back along the track without the box (panel 4).

in two 5-minute bouts with a 1-minute rest period separating the work bouts. Performance was recorded as the total distance covered during the task.

Anthropometry

Body weight was determined to the nearest 0.05 kg on a calibrated load cell platform with digital indicator (Model WS2000, Western Scale Co., San Diego, CA). Men were weighed in shorts, women in shorts and t-shirt. Stature was measured to the nearest 0.1 cm using a wall-mounted retractable tape measure with Broca plane attached. Participants were barefoot, stood with heels together, took a deep breath, and "stretched tall" while the Broca plane was placed on the vertex of the head and measurement taken.

Body composition

Body volume was determined by hydrodensitometry (underwater weighing; Goldman and Buskirk, 1961) with adjustment for residual volume, measured by helium dilution before underwater weighing (Rupple, 1975)). Body density was determined from body volume and body mass (Buskirk, 1961). Body fat content, as a percentage of body mass, was estimated using the equation of Siri (1961). Fat mass (FM) and fat-free mass (FFM) were calculated from body fat content and body mass.

Analysis.

Comparisons of mean values for men and women in this sample were carried out using the Student's t-test for groups. Prediction models were developed using multiple regression. Regressions were usually run in a stepwise fashion. The regression was stopped when the next variable to enter accounted for less than 2% of the variance. The identity of regression lines between genders was tested using analysis

of variance. All statistics were calculated and statistical tests run using SPSS, version 8.0 for windows. Significance was accepted for values of $p < 0.05$.

Results

Table 3. Performance Results[1]

Item	*Males* (n = 64)		Females *(n = 38)*		Total Sample *(n = 102)*	
Aerobic Measures						
VO2max (ml/kg/min)	50.4[2]	(6.8)	44.4	(7.5)	48.1	(7.6)
VO2max (L/min)	4.06[2]	(0.58)	2.70	(0.41)	3.53	(0.84)
1.5-mi. run time (min)	11.5	(2.3)	13.4	(2.4)	12.2	(2.5)
Strength						
Handgrip (kg)	41.9	(6.8)	28.0	(3.6)	36.8	(8.9)
Arm-pull (kg)	31.5	(5.4)	21.0	(2.6)	27.7	(6.9)
Arm-lift (kg)	49.5	(7.4)	35.7	(8.3)	44.8	(8.6)
Arm curl (kg)	37.4	(8.6)	15.3	(3.7)	29.1	(12.9)
Lat Pull-down (kg)	70.8	(15.2)	34.9	(6.5)	57.4	(21.6)
Bench press (kg)	72.6	(18.8)	33.0	(6.14)	57.8	(24.6)
Shoulder press (kg)	57.4	(12.1)	29.7	(5.5)	47.1	(16.8)
Leg press (kg)	197.3	(40.7)	128.3	(29.6)	171.6	(49.8)
Incremental Lift (kg)	61.6	(13.4)	32.3	(5.4)	50.6	(18.0)
Job Tasks						
Lift to knuckle height (kg)	93.2[3]	(17.6)	60.3	(13.4)	80.5	(22.7)
Lift to elbow height (kg)	65.8[2]	(11.9)	40.2	(6.9)	55.9	(16.2)
Box carry distance (m)	1134.6[4]	(148.0)	997.3	(134.4)	1082.4	(157.3)

[1] Values shown are means and (1 SD), all means differed significantly (p <0.05) between genders.
[2] n = 60, [3] n = 61; [4] n = 62

Table 3 provides the mean values for performances on the physical fitness and job-task measures for this study. Except for curl-ups, there were significant gender differences in all performance means.

Table 4 provides the correlation coefficients for the associations between the strength measures and performance of the job tasks. The best single predictor of the lifting tasks was the ILM. Comparison of the correlations between ILM and lifting were similar to correlations between the lifts and the sum of

Table 4. Correlations between strength measures and job task performances

Measure	Lift to knuckle ht.	Lift to elbow ht.	Box Carry Distance
Arm Curl	0.80	0.88	0.54
Bench Press	0.76	0.85	0.57
Shoulder Press	0.80	0.88	0.52
Lat Pull-down	0.80	0.86	0.57
Leg Press	0.76	0.76	0.48
ILM	0.85	0.89	0.52

any two pairs of the other measures. Because of this findings and because this task is similar to one already in use by the military (Air Force, SAT), it was decided to use the ILM 1RM as the measure of strength for the purposes of this paper.

Table 5. Correlations* between body composition variables, strength, and task performances

	1.	2.	3.	4.	5.	6.	7.
1. Knuckle-ht. lift	-						
2. Elbow-ht. lift	**0.86**	-					
3. Box Carry	**0.55**	**0.57**	-				
4. Fat-free mass	**0.79**	**0.84**	**0.53**	-			
5. Fat mass	0.03	0.09	**-0.30**	0.08	-		
6. % fat	**-0.31**	**-0.28**	**-0.51**	**-0.35**	**0.89**		
7. Body mass	**0.66**	**0.73**	**0.28**	**0.86**	**0.58**	0.17	
8. ILM	**0.85**	**0.89**	**0.52**	**0.88**	0.07	**-0.31**	**0.75**

* Correlations indicated in bold are significant ($p < 0.05$).

Table 5 shows the correlations between among FFM, FM, body fat content and task performance. As expected, the fat-free mass is highly correlated with the lifting tasks, and moderately correlated with the carry task. The fat mass is uncorrelated with the lifts and negatively correlated with the box carry.

Table 6. Results of Analysis of Variance to determine gender differences in regressions

Predictor	*Regression (Predictor)*		*Intercept (Gender)*		*Slope (Gender by Predictor)*	
	F	Signif.	F	Signif.	F	Signif.
Lift to knuckle height[1]						
ILM	34.08	<0.001	1.39	0.241	0.89	0.349
Fat-free mass	13.92	<0.001	0.78	0.379	1.30	0.257
Body mass	6.39	0.013	0.09	0.759	0.38	0.538
Lift to elbow height[2]						
ILM	35.47	<0.001	0.90	0.346	0.07	0.795
Fat-free mass	16.24	<0.001	0.97	0.326	2.11	0.150
Body mass	9.46	0.003	0.00	0.965	1.30	0.257

[1] Degrees of freedom are 1,95
[2] Degrees of freedom are 1,94

Table 7. Regression Results

Criterion (kg)	Predictor (kg)	Regression weight	Regression Constant	R^2	Standard. Error of Estimate
Lift to knuckle height:					
	ILM	1.06	27.04	0.72	11.99
	FFM	1.52	-8.57	0.63	13.97
	WT	1.04	4.02	0.44	17.11
Lift to elbow height:					
	ILM	0.81	15.44	0.79	7.48
	FFM	1.15	-11.50	0.71	8.81
	WT	0.81	-3.84	0.53	11.13

Prediction of Lifting:

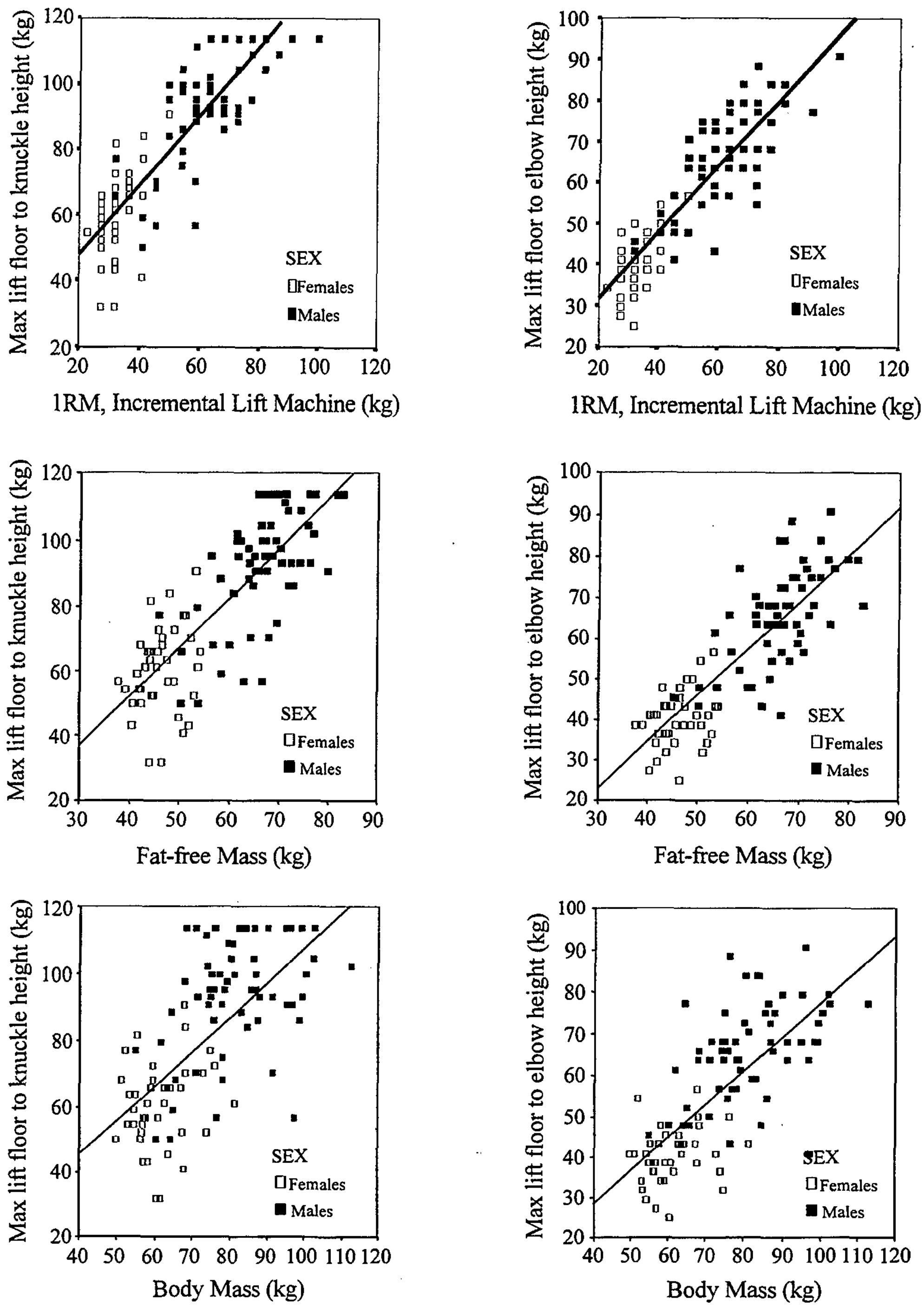

Figure 3. Relationships between lifting capacity to knuckle height and elbow height and ILM 1RM, FFM, and body mass. (See text.)

Based on the pattern of correlations between body composition variables and lifting performance, only FFM was considered as a predictor of the box lifts. Table 6 shows the results of the analysis of

variance to test for identity of regression lines between genders. The regressions did not differ between genders for either of the lifts.

The results of the multiple regression are provided in Table 7. In general the strength measure was the best predictor of lifting ability, but FFM predicted almost as well. FFM accounted for 9% less of the variance in the knuckle-height lift and 8% less of the variance in the elbow-height lift, compared to ILM. Body mass was a poor predictor of lifting capacity, compared to either ILM or FFM.

On the average, participants in this study were able to lift 1.36 times their FFM to knuckle height (SD = 0.25). Women were able to lift 1.31 times their FFM (SD = 0.28), and men 1.40 times FFM (0.22). This difference approached ($p = 0.06$) but did not attain significance. Participants were able to lift 0.94 times their FFM to elbow height on average (SD = 0.15). For women the value was 0.87 (0.14), and men 0.99 (0.14). This difference was significant ($p < 0.05$).

The relationships described in Table 7 are shown graphically in figure 3. In figure 3, the left most panels depict relationships with lifting capacity to knuckle height, the rightmost, lifting capacity to elbow height. The topmost panels show relationships to 1RM measures on the incremental lift machine, the middle panels, to fat-free mass, and the lower panels, to body mass.

Prediction of Box Carry Distance:

The correlation results shown in Table 4 indicate that among the body composition variables, fat-free mass, fat mass, percent body fat, and body mass are significant predictors of box carry distance. These variables were entered into a multiple linear regression to predict the carry distance. The result is equation (1).

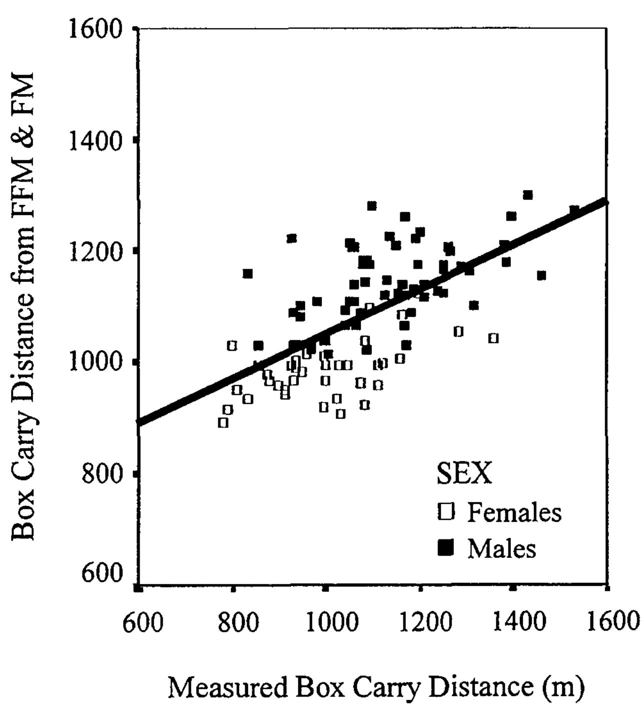

Figure 4. Scatterplot of box carry distance predicted from FFM and FM with measured box carry distance. Line indicates least squares regression for the whole sample.

Box carry distance = 7.463 x fat-free mass - 7.367 x fat mass + 752.886 (1)

The squared multiple correlation for this model (R^2) = 0.403, and the standard error of estimate = 122.78 m. Fat mass was a slightly better predictor with fat-free mass than was percent fat ($R^2 = 0.400$, see = 123.08 m). Models that included body mass as a replacement for either fat-free mass or fat mass fit equally well. This is because both fat-free and fat masses are derived from body mass using the percent fat value. Thus, the masses are all directly, linearly related to one another. Once one of them has entered a regression, the remaining variance associated with fat and lean, can be accounted for by any remaining mass measure. Another way of expressing this relationship is, given any one of the measures, the partial correlation between the other two is 1.0.

The regression lines were tested for gender differences. Significant differences were not found for differences in intercept ($F_{1,94} = 0.37$, $p = 0.543$) or slope ($F_{2,94} = 0.51$, $p = 0.604$).

As anticipated, the fat-free mass is positively related to performance, and the fat mass, negatively related. The two masses are approximately equal in the magnitude of their effect. Figure 4 is a scatter-plot of predicted and measured box carry distances.

Discussion

The results of this study indicate that performance of materials handling tasks requiring strength can be predicted rather well from fat-free mass. All the Services have the techniques to determine fat-free mass, because they each monitor weight control by use of height and weight measurement, and have circumference-based equations to estimate percent body fat. Thus fat-free mass is readily available in instances when estimation of strength is required. In this study, fat-free mass was determined from percent fat based on underwater weighing. While beyond the scope of this paper, performances should be predicted almost as well from fat-free mass derived from anthropometric equations. In this sample, the squared correlation coefficient between fat-free mass from underwater weighing and that from anthropometrically determined percent fat using the current U.S. Navy equations (Hodgdon and Beckett, 1984a, 1984b) is 0.955, with a standard error of measurement of 2.5 kg. Furthermore, the slope of the regression is not statistically different from a value of 1.0.

Prediction of lifting.

The results of this study are in agreement with the work of Teves and coworkers (1985), Meyers and coworkers (1983), and others who have found strong positive associations between fat-free mass and lifting capacity. In general, the correlation coefficients reported here are somewhat higher than those reported by others. It is believed that that results from having pooled the data from the men and women. This would increase the variance of the sample and inflate the correlation coefficients. In this sample, the coefficient for the correlation between lift to elbow height and fat-free mass is 0.61 for men, and 0.29 for women. Values for the lift to knuckle height are 0.59, and 0.24 for men and women, respectively. These values are comparable to previous reports.

As expected, the fat mass was not at all related to lifting ability. While lifting does involve movement of the center of mass, and with it, accompanying movement of the fat mass, this movement is small compared to the moments that are generated in the limbs to move the object being lifted. In our study as in others (Teves, Wright and Vogel, 1985; Sharp, 1992: Meyers, et al, 1983) negative correlation coefficients in the range of 0.2-0.3 between percent body fat and lifting capacity have been determined. It is probably the information related to the proportioning of mass between fat and non-fat that creates this association. Higher percent fat values are associated, in general, with a lower fat-free mass.

In this sample, fat-free mass is a much more precise indicator of strength or lifting capacity than is body mass (see Table 5). While not surprising, it is a reminder that size is not the preferred attribute when strength is what is required, and that large fat workers are not always more capable than smaller, leaner ones.

The correlation coefficient between ILM 1RM and fat-free mass is 0.88. This means only 78 percent of the variance in ILM performance was associated with variation in fat-free mass. The standard error of the estimate for the prediction of ILM from fat-free mass is 8.5kg. This value is equal to 1.87 weight plates on the ILM, and suggests that fat-free mass is not a very precise indicator of ILM performance. Use of fat-free mass in prediction of lifting capacity only increases the standard error of estimate

by 2.0 kg for the lift to knuckle height, and 1.3 kg for the lift to elbow height, compared to ILM-based predictions. Therefore, fat-free mass values may be suitable for prediction of lifting tasks, particularly when strength testing is not feasible.

Practical Implementation.

Table 8. Logistic regressions to predict probability of completing lifts*

Mass lifted (kg)	a_0	(SE a_0)	a_1	(SE a_1)
to knuckle height				
50	-4.4623	(2.2079)	0.1261	(0.0453)
60	-6.4482	(1.6900)	0.1411	(0.0330)
70	-10.6325	(1.9908)	0.1993	(0.0365)
80	-13.7801	(2.5115)	0.2354	(0.0420)
90	-15.4076	(3.0725)	0.2481	(0.0485)
100	-14.5907	(3.5449)	0.2046	(0.0517)
to elbow height				
40	-9.1934	(2.5844)	0.2069	(0.0542)
50	-17.2829	(3.2908)	0.3018	(0.0567)
60	-15.5533	(3.0979)	0.2519	(0.0491)
70	-14.0684	(3.3907)	0.1977	(0.0497)

* a_0 is the regression constant, a_1 the regression weight for FFM (see the equation in the text).

Jackson (1994) has suggested that one way of dealing with setting standards based on regression equations is to transform them into probabilities derived from logistic regression. Logistic regression provides a methods of relating a dichotomous outcome (success/failure) to a continuously scaled measure. The form of the logistic equation is $\text{Odds of an event} = e^{(a_0 + a_1 \times x_1 + a_2 \times x_2 + \ldots + a_k \times x_k)}$, where a1 through ak are regression weights for variables x1 through xk, and a0 is the regression constant. The probability that an event will happen = $\dfrac{e^{(a_0 + a_1 \times x_1 + a_2 \times x_2 + \ldots + a_k \times x_k)}}{1 + e^{(a_0 + a_1 \times x_1 + a_2 \times x_2 + \ldots + a_k \times x_k)}}$. In the case of maximal lifting, a series of regressions can be carried out to generate a table of probabilities based on specific weights lifted. This was done for the knuckle and elbow lifts based on the data from this study. Table 8 contains the logistic regression equations. A sample table of results is provided as Table 9, which contain probabilities of completing lifts to knuckle height. Also indicated on the table is a hypothetical selection point. The table is marked to select individuals is selected who have a 75 percent chance of completing the lift. This level was chosen arbitrarily, as a possible cut-point. Cells in which the probability value exceeds 0.75 have been shaded. Such a scheme makes it easy to determine the FFM needed for a particular knuckle height lift. Table 10 provides similar information for the lift to elbow height.

This approach would require the construction of tables for lifts to different relative or absolute heights. Additional work would have to be done to incorporate models such as those of Monod (1985) which take repeated lifting into account, and the findings of Sharp and coworkers (1997) which allows some adjustment for use of a team to lift. The modeling of lifting and other materials handling tasks may also be improved by consideration of regional distributions of muscle and fat masses. Fat-free mass is a global indicator of the amount of non-fat tissue. Technologies such as dual-energy X-ray absorptiometry (DXA) and magnetic resonance imaging (MRI), can allow more precise tissue definition as well as information about their distributions within the body. Such technologies should be employed to enhance our understanding of the anatomical and physiological determinants of performance.

Table 9. Probability of lifting selected weights to knuckle height.

	Weight to be lifted (kg)					
Fat-free mass (kg)	50	60	70	80	90	100
40	0.64	0.31	0.07	0.01	0.00	0.00
45	0.77	0.48	0.16	0.04	0.01	0.00
50	0.86	0.65	0.34	0.12	0.05	0.01
55	0.92	0.79	0.58	0.30	0.15	0.03
60	0.96	0.88	0.79	0.59	0.37	0.09
65	0.98	0.94	0.91	0.82	0.67	0.22
70	0.99	0.97	0.97	0.94	0.88	0.43
75	0.99	0.98	0.99	0.98	0.96	0.68
80	1.00	0.99	1.00	0.99	0.99	0.86
85	1.00	1.00	1.00	1.00	1.00	0.94
90	1.00	1.00	1.00	1.00	1.00	0.98

Box-carry task.

Table 10. Probability of lifting selected weights to knuckle height.

	Weight to be lifted (kg)			
Fat-free mass (kg)	40	50	60	70
40	0.29	0.01	0.00	0.00
45	0.53	0.02	0.01	0.01
50	0.76	0.10	0.05	0.02
55	0.90	0.34	0.15	0.04
60	0.96	0.70	0.39	0.10
65	0.99	0.91	0.69	0.23
70	0.99	0.98	0.89	0.44
75	1.00	1.00	0.97	0.68
80	1.00	1.00	0.99	0.85
85	1.00	1.00	1.00	0.94
90	1.00	1.00	1.00	0.98

The results of the box carry task offer additional support for the work of Cureton (1992) and others (Beckett and Hodgdon, 1987a; Mello, et al, 1988; Dziados, et al, 1987) who have shown that for tasks which involve moving the body, greater fat-free mass is associated with better performance, and greater fat mass with worse performance. However, results such as these are difficult to utilize in present form. There are an infinite variety of carrying tasks, differing in mass carried, distance, velocity, and frequency of performance. Methods to simplify the expression of the parameters of the carrying task need to be developed.

Additionally, there are other physiological parameters which need to be considered. Beckett and Hodgdon (1987b) have shown for this sample that prediction of the carry task is improved when an indicator of aerobic capacity such as 1.5-mile run time is included in the regression. The overall R^2 is increased from 0.403 to 0.533 when the predictors are FFM and , and to 0.555 when the predictors are FFM and 1.5-mile run time. The slight improvement in prediction with the inclusion of run time rather

than may be because the run time reflects performance of a task which is positively dependent of FFM and negatively dependent on fat mass. The run time includes some of the variance related to the fat mass, which did not enter into the regression.

Conclusions

The results of this study suggest the fat-free mass is a predictor of lifting capacity, suitable for strength assessment when direct measures are not available. In addition, this study confirms previous work that indicates that performance of tasks that involve translation of the body are positively related to fat-free mass and negatively related to fat mass.

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The Services, have, for 16 years, used body composition as the basis for weight control policy. There is a familiarity with the concepts and notions of the nature of body composition within the Services. Body composition variables, specifically fat-free mass and fat mass have been shown to be related to materials handling performances. It is the purpose of this report to determine these relationships, and suggest ways in which they might be used for safe, field deployable methods for estimation of materials handling performance. It appears that fat-free mass can be used to estimate ability to perform manual materials handling tasks. In the case of lifting, logistic models can be used to determine acceptable levels of fat-free mass for specific tasks: lifting heights and weights. In the case of carrying tasks, simplifying principles need to be developed before predictive models can be developed.

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